

# Development of HPD Clusters for MAGIC-II

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**Abstract.** MAGIC-II is the second imaging atmospheric Cherenkov telescope of MAGIC which is located on Canary island of La Palma. We are currently developing a new camera based on clusters of hybrid photon detectors (HPD) for the upgrade of MAGIC-II. The photon detectors feature a GaAsP photocathode and an avalanche diode as electron bombarded anodes with internal gain, and were supplied by Hamamatsu Photonics K.K. (R9792U-40). The HPD camera with high quantum efficiency will increase the MAGIC-II sensitivity and lower the energy threshold. The basic performance of the HPDs has been measured and a prototype of an HPD cluster has been developed to be mounted on MAGIC-II. Here we report on the status of the HPD cluster and the project of eventually using HPD clusters in the central area of the MAGIC-II camera.

**Keywords:** Hybrid Photon Detector, Imaging Atmospheric Cherenkov Telescope

## I. INTRODUCTION

MAGIC[1] is an observatory of two imaging atmospheric Cherenkov telescopes (IACT) for ground-based very high energy gamma-ray astronomy. It is located on Canary island of La Palma(28.75°N, 17.86°W, 2225 m a.s.l.). The first telescope, MAGIC-I is in operation since 2004. Stereoscopic observation with the second telescope, MAGIC-II, is planned to start in 2009[2]. Using the two telescopes with mirrors of 17 m diameter, the sensitivity of MAGIC is improved by at least a factor of 2[3]. The current camera of MAGIC-II consists of 1039 pixels of Hamamatsu R10408 photomultipliers (PMT) with a super-bialkali photocathode[4]. To achieve a higher gamma-ray sensitivity with MAGIC-II, we plan to use a new camera consisting of photon detectors with higher performance[1][5][6][7]. One of the promising candidates for the new photon detector is a hybrid photon detector (HPD) with high quantum efficiency (QE). For MAGIC-II Hamamatsu Photonics K.K. has recently developed Hamamatsu R9792U-40 HPD with a GaAsP photocathode in collaboration with MPI Munich. We have measured the basic performance of the R9792U-40[8][9], and developed a cluster to be mounted on the

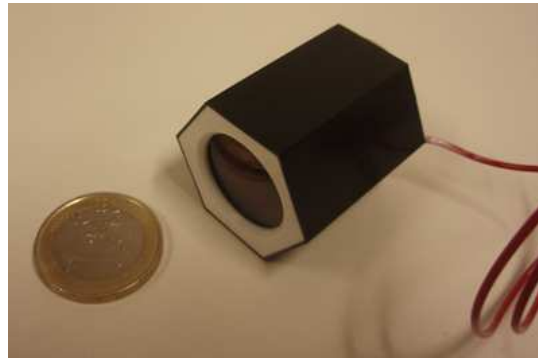


Fig. 1. Photograph of Hamamatsu R9792U-40 HPD.

MAGIC-II camera for gaining experience in operation on IACTs. Here we report on the studies with a single HPD and the prototype of the cluster to be tested on MAGIC-II. We also report on the plan to build a new camera with HPDs for MAGIC-II.

## II. PERFORMANCE OF THE HAMAMATSU R9792U-40 HPD

Figure 1 shows a photograph of the Hamamatsu R9792U-40 HPD of a compact, hexagonal structure. The Hamamatsu R9792U-40 HPD consists of a GaAsP photocathode and a 3 mm diameter avalanche diode (AD) acting as an electron bombarded anode with additional internal gain. The diameter of the photocathode with uniform sensitivity is  $\sim 18$  mm. The bombardment and avalanche gain of the HPD R9792U-40 are  $\sim 1550$  and  $\sim 50$  respectively, when biasing the photocathode at  $-8$  kV and the AD at 400 V. There are several important advantages of using the HPD R9792U-40 for IACTs. The first one is the high quantum efficiency of the GaAsP photocathode, which is above 50 % at 500 nm as shown in Fig. 2. The QE in UV region (300 - 400 nm) is rather low but can be increased by a wavelength shifter coating, which is a mixture of 0.03 g POPOP and 0.03 g butyl-PBD as a wavelength shifter, and 1.5 g of Paraloid B72 (an acrylic lacquer base) as a binder. This mixture is dissolved in Toluene (or similar solvent of medium evaporation speed at room temperature) and applied as a thin layer onto the window. After the evaporation

of the Toluene, a hard layer is formed. In addition to the high QE, the photoelectron collection efficiency of the HPD R9792U-40 is almost 100 % because of the electrode structure and very high acceleration voltage. By using the HPD R9792U-40, we should obtain twice as many photoelectrons from atmospheric Cherenkov light as compared with the MAGIC-I camera PMTs. Figure 3 shows the photoelectron resolution measured with an HPD R9792U-40. The pulse width of a narrow light flash illuminating the HPD R9792U-40 is 2.1 nsec (FWHM), which is about the typical time spread of Cherenkov light from low energy gamma showers, i.e. it is fast enough to enable proper operation under the night sky background (NSB) maximizing signal-to-noise ratio. The lower afterpulse rate of HPD R9792U-40 compared to standard PMTs is also a key feature to minimize fake triggers. The AD shows quite some gain dependence on temperature changes. Therefore we have implemented a thermistor on the copper ring, which is thermally coupled to the AD and corrects the bias voltage thus successfully compensates the temperature dependence of the AD gain, reducing it to an acceptable stability of  $\sim 0.3\%/^{\circ}\text{C}$  in the temperature range between 25 to  $35^{\circ}\text{C}$ . Figure 4 shows both the temperature-compensated and uncompensated AD gain as a function of the operating temperature. The aging of the photosensors due to the rather NSB is also an important issue. We have estimated the expected lifetime of the GaAsP photocathode to be more than 10 years operation under the dark night condition. Figure 5 represents the result of the lifetime estimation of HPD R9792U-40 from an accelerated aging test exposing the HPD to continuous light, which is 30~50 higher brighter than the nominal NSB. Here we define the lifetime as the period in which the QE degrades by 20 %. A long lifetime was realized by suppressing ion feedback in the HPD R9702U-40 by a very high vacuum and a special ion deflector close to the AD[10]. We have also implemented a protection circuit against strong light like from car headlights during observation, as shown in Fig. 6. All the basic performance parameters of HPD R9792U-40 seem to satisfy the requirements to operate such photon detectors on IACTs.

### III. DEVELOPMENT OF THE HPD CLUSTER

To evaluate the HPD performance of the MAGIC-II camera, we have developed an HPD cluster module consisting of seven HPDs. Figure 7 shows a prototype of the HPD cluster module. The geometry and interface of the HPD cluster are compatible to the current PMT cluster[4], i.e. plug exchangeable for possible future replacements. The HPD cluster module consists of an HPD, thermistor, preamp, VCSEL chip, DCDC-converters for the AD and photocathode, light catchers and slow control cluster processor (SCCP). Figure 8 shows a schematic view of the HPD cluster module. The AC coupled signal from the HPD is fed to a preamplifier with 25 dB amplification and 700 MHz bandwidth

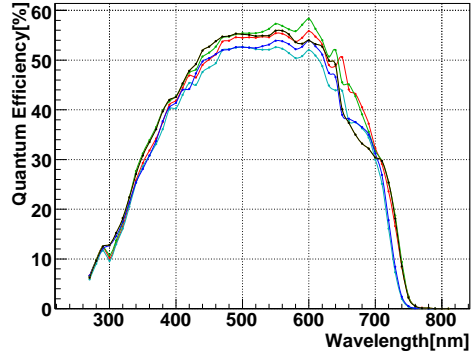


Fig. 2. QE of the HPD R9792U-40 as a function of the wavelength.

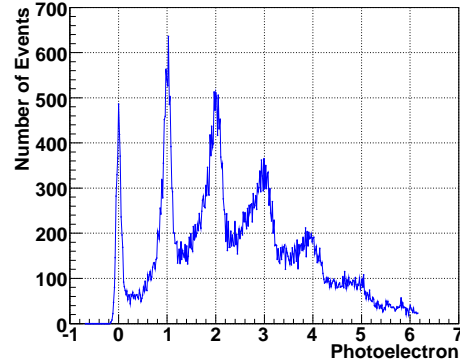


Fig. 3. Single photoelectron resolution measured with HPD R9792U-40.

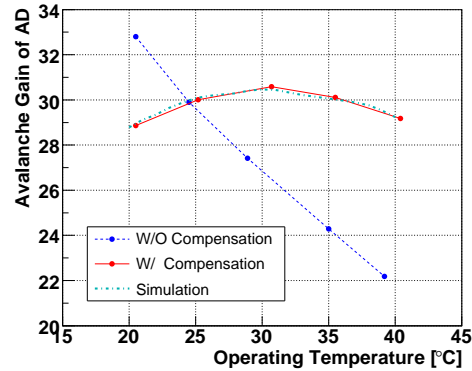


Fig. 4. Temperature compensation of HPD R9792U-40.

(SIRENZA, SGA-5586). A test pulse system is also implemented to check the entire signal chain including the digitization and the readout. The amplified pulse signal is fed to the VCSEL chip (Avalon AVAP-850SM), which is the acronym for vertical-cavity surface-emitting laser and converts the electric signal to 850 nm wavelength optical signal. The optical signal is transferred to the counting house with 160 m multi-mode optical fibers. The VCSEL board is firmly mounted to the cooling plate of the camera for proper temperature stabilization.

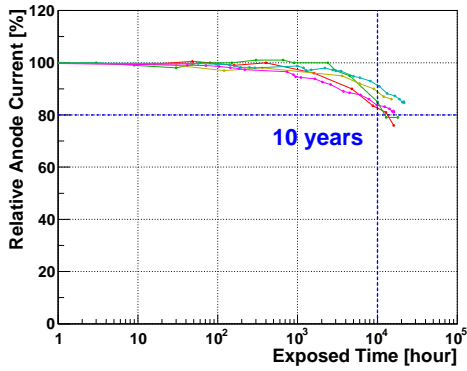


Fig. 5. Lifetime estimation of HPD R9792U-40.

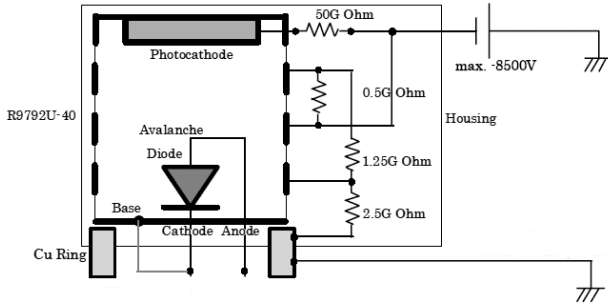


Fig. 6. Protection circuit implemented to HPD R9792U-40.

The SCCP[11] controls the DCDC converters (SDS APD Series for 400 V and SDS HPDB5802300 for -8 kV), and the current of the VCSEL chip. The DC current due to the steady flux of the NSB in the AD of the HPD, the current and temperature of the VCSEL, are also monitored via SCCP. The SCCP consists of a micro-controller chip (AMTEL AT89C51ID2), a 12bit ADC, and DAC. Each SCCP is connected to a VME board located in the camera with LAN cable (RJ45 connector). The VME board in the camera is connected to the PC in the counting house with an optical PCI to VME link (Strück SIS3100). The thermistor, preamp, VCSEL chip and 500 V DCDC converters are placed in seven cylindrical aluminum tubes used for EMI shielding. The -8 kV DCDC converters are common for all seven HPDs and placed next to the SCCP in the aluminum cluster body with careful high voltage insulation. “Light catchers”, similar to Winston cones, are used to provide nearly 100% light concentration onto the photocathodes and shield against large angle stray light. Figure 9 shows a photograph of the HPD cluster and the light catchers. For using light catchers in contact with the HPD glass window with high voltage on the inner side, we have developed a novel non-conductive UV-reflective dielectric film in collaboration with Fraunhofer Institute[12]. As base material we use the 3M Vikuiti ESR2 foil with nearly 100 % reflectivity between 385 and 750 nm. For extending the high reflectivity down to 300 nm, the foil is overcoated with 40 alternative

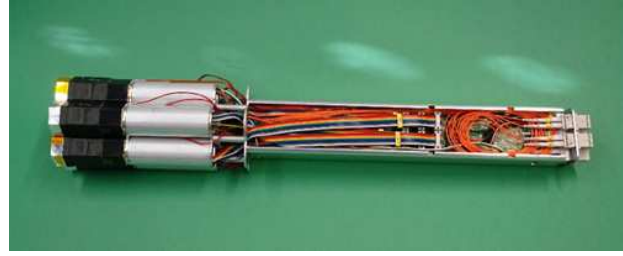


Fig. 7. Side view of the HPD cluster for MAGIC-II.

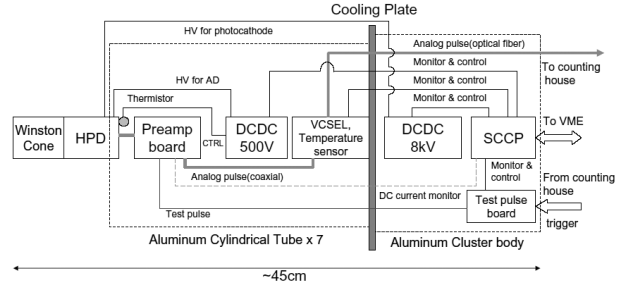


Fig. 8. Schematic view of the HPD cluster module for MAGIC-II.

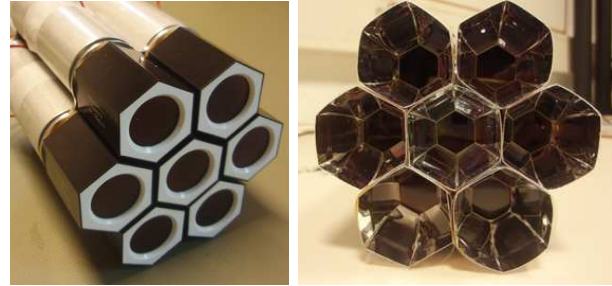


Fig. 9. Front view of the HPD cluster for MAGIC-II without (left) and with light catchers (right). The light catchers are made using the non-conductive UV-reflective dielectric film.

layers of  $\text{SiO}_2$  and  $\text{HfO}_2$ . Currently, a mean reflectivity of 95 % has been achieved when averaging from 300 to 750 nm. The film for the light catcher is cut by laser and assembled to a hexagonal shape using special tools. As in the current MAGIC-II camera the amplified signals are back-converted by VCSELs to optical signals, which are sent by optical fibers to the receiver[13] in the counting house and fed to the data acquisition system consisting of Domino Ring Sampler[14]. The Cherenkov signals are digitized with 2GSample/s.

#### IV. FUTURE PLAN

As the first stage, we will mount six HPD cluster modules (42 pixels) on the corners of the MAGIC-II camera. Once a satisfactory performance of the HPD cluster is confirmed, more clusters will be mass-produced and the central 61 clusters with classical PMTs (427 pixels) of the MAGIC-II camera will be replaced in the near future by HPD ones.

## V. CONCLUSION

A new camera of Hamamatsu R9792U-40 HPDs is presently under construction for future upgrades of the MAGIC-II telescope. The basic performance parameters of HPDs were tested and it has been found that they fulfill the requirements to be used on IACTs. We have developed an HPD cluster of seven HPDs with all the associated electronics. The cluster is plug-compatible to the current PMT clusters of the MAGIC-II camera. It is planned to replace the central region of the current MAGIC-II camera by HPD clusters in future to enhance the gamma-ray sensitivity. The status of the HPD development for MAGIC-II has been reported.

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